IS 9001-11 (1973): GUIDANCE FOR ENVIRONMENTAL TESTING, Part 11: solar radiation test [LITD 1: Environmental Testing Procedure]

BLANK PAGE

Indian Standard

GUIDANCE FOR ENVIRONMENTAL TESTING

PART 11 SOLAR RADIATION TEST

Second Reprint JUNE 1993
(Incorporating Amendments No. 1 & 2)

UDC 621·31+621·38·038 : 620·193·6

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Gr 5 *January* 1974

Indian Standard

GUIDANCE FOR ENVIRONMENTAL TESTING

PART 11 SOLAR RADIATION TEST

Environmental Testing Procedures Sectional Committee, ETDC 26

Chairman	*Representing*
BRIG D. SWAROOP	Ministry of Defence, New Delhi
Members	
ADDITIONAL DIRECTOR STANDARDS (S & T)	Research, Designs & Standards Organization, Ministry of Railways, Lucknow
JOINT DIRECTOR STANDARDS (S & T) (*Alternate*)	
SHRI H. K. L. ARORA	All India Radio & Electronics Association, Bombay
SHRI R. G. KESWANI (*Alternate*)	
SHRI ARUP CHAUDHURI (*Alternate*)	
SHRI H. R. BAPU SEETHARAM	Bharat Electronics Ltd, Bangalore
SHRI P. S. K. PRASAD (*Alternate*)	
DR A. S. BHADURI	National Test House, Calcutta
SHRI B. P. GHOSH (*Alternate*)	
SHRI G. A. CLAYDON	Lucas-TVS Ltd, Madras
SHRI B. K. BANERJEE (*Alternate*)	
DR B. N. DUTTA	Directorate General of Observatories (Ministry of Tourism & Civil Aviation), New Delhi
DR P. K DUTTA	Philips India Limited, Bombay
SHRI D. B. N. MURTHY (*Alternate*)	
GENERAL SECRETARY	Society of Environmental Engineers, Bangalore
SHRI C. G. SUBRAMANYAN (*Alternate*)	
SHRI GHASITA SINGH	Central Electronics Engineering Research Institute (CSIR), Pilani
SHRI G. R. GHOSH	Ministry of Defence (DGI)
SHRI SARDUL SINGH (*Alternate*)	
SHRI JOHN FRANCIS	Posts and Telegraphs Board, New Delhi
SHRI R. N. PATNEY	Radio Electronic & Television Manufacturers' Association, Calcutta
SHRI K. S. SODHI (*Alternate*)	
SHRI D. V. PETKAR	Bhabha Atomic Research Centre, Bombay
SHRI R. RAMACHANDRAN	National Radio & Electronics Co Ltd, Bombay
SHRI P. SANDELL	All India Instrument Manufacturers' & Dealers' Association, Bombay
SHRI V. K. VASUDEVAN (*Alternate*)	
SHRI N. S. SATHYANARAYANAN	Indian Telephone Industries Ltd, Bangalore
SHRI K. VAIDYANATHAN (*Alternate*)	

(*Continued on page* 2)

(*Continued from page* 1)

Members	*Representing*
SHRI D. SEN GUPTA	Directorate of Inspection (Vehicles), Ministry of Defence (DGI)
SHRI S. R. MURTHY (*Alternate*)	
SHRI R. SOMASUNDARAM	Directorate of Technical Development & Production (Air), Ministry of Defence, New Delhi
SHRI A. V. RAJU (*Alternate*)	
DR Y. SOMAYAJULU	National Physical Laboratory (CSIR), New Delhi
SHRI P. SURYANARAYANA (*Alternate*)	
LT-COL T. R. K. SUNDARAM	Ministry of Defence (R & D)
SHRI T. G. SRINIVASAN (*Alternate*)	
CDR C. K. VISWANATH	Naval Headquarters
LT-CDR J. J. BAXI (*Alternate*)	
SHRI U. V. WARLU	Electronics Corporation of India Ltd, Hyderabad
SHRI N. SRINIVASAN, Deputy Director (Elec tech) (*Secretary*)	Director General, BIS (*Ex-officio Member*)

Panel for Solar Radiation, ETDC 26 : P2

Convener	
SHRI P. S. K. PRASAD	Bharat Electronics Ltd, Bangalore
Members	
SHRI G. A. CLAYDON	Lucas-TVS Ltd, Madras
SHRI B. K. BANERJEE (*Alternate*)	
SHRI G. R. GHOSH	Ministry of Defence (DGI)
SHRI SARDUL SINGH (*Alternate*)	
DR J. N. NANDA	Defence Research Laboratory (Material), Ministry of Defence (R & D), Kanpur
SHRI B. R. YADAV	Directorate General of Observatories (Ministry of Tourism & Civil Aviation), New Delhi

Indian Standard

GUIDANCE FOR ENVIRONMENTAL TESTING

PART 11 SOLAR RADIATION TEST

0. FOREWORD

0.1 This Indian Standard (Part 11) was adopted by the Indian Standards Institution on 6 July 1973, after the draft finalized by the Environmental Testing Procedures Sectional Committee had been approved by the Electrotechnical Division Council.

0.2 This standard has been largely based on IEC Document 50 (Central Office) 171 'Draft guidance on solar radiation testing', issued by the International Electrotechnical Commission.

0.3 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test, shall be rounded off in accordance with IS : 2-1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

---

1. SCOPE

1.1 This standard (Part 11) gives guidance regarding test for effects of solar radiation on electronic and electrical equipment and components at the surface of the earth.

2. OBJECT

2.1 This standard describes methods of simulation designed to examine the effect of solar radiation on equipment and components at the surface of the earth. The main quantities to be simulated are the spectral energy distribution of the sun as observed at the earth's surface and the intensity of received energy, in combination with controlled temperature conditions. However, it may be necessary to consider combination of solar radiation, including sky radiation, with other environments, for example, temperature, humidity and air velocity.

*Rules for rounding off numerical values (*revised*).

3. IRRADIANCE AND SPECTRAL DISTRIBUTION OF TEST SOURCE

3.0 The effect of radiation on the specimens will depend on the level of irradiance and its spectral distribution.

3.1 Irradiance — The irradiance by the sun on a plane perpendicular to the incident radiation outside the earth's atmosphere at the mean earthsun distance is known as the solar constant *Io*.

The irradiance at the surface of the earth is influenced by the solar constant and the attenuation and scattering of radiation in the atmosphere. For test purposes, a value of 1·120 kW/m² for the global (total) radiation at the surface of the earth from sun and sky, with the sun at zenith, based on a solar constant $Io = 1{\cdot}35$ kW/m² has been recommended (*see* Note).

NOTE — This value has been recommended by the International Commission on Illumination (CIE).

3.2 Spectral Distribution — The standard spectral distribution of the global radiation specified for this test is given in Table 1 of IS : 2106 (Part XVII)-1973*. Where only the thermal effects of solar radiation are of interest, the use of tungsten filament lamps may be permitted. However, it shall be clearly understood that the spectral distribution of tungsten filament lamps differs markedly from that of natural solar radiation (*see* Fig. 1) and the irradiance shall be adjusted in accordance with **3.3**.

3.3 Irradiance to be Used with Other Spectral Distribution — If the source of radiation used for the test does not meet the spectral distribution given in Table 1 of IS : 2106 (Part XVII)-1973*, for example, where tungsten filament lamps are used (permissible if the test is solely to assess thermal effects), the irradiance shall be adjusted so that the heating effect is the same as if the test specimen(s) were irradiated by the global radiation of sun and sky. Therefore, the absorbed radiation from the test source shall be the same as for the global radiation of sun and sky (*see also* Appendix);

that is

$$E_{ex} = 1{\cdot}120 \frac{\alpha_{es}}{\alpha_{ex}} \text{kW/m}^2$$

where

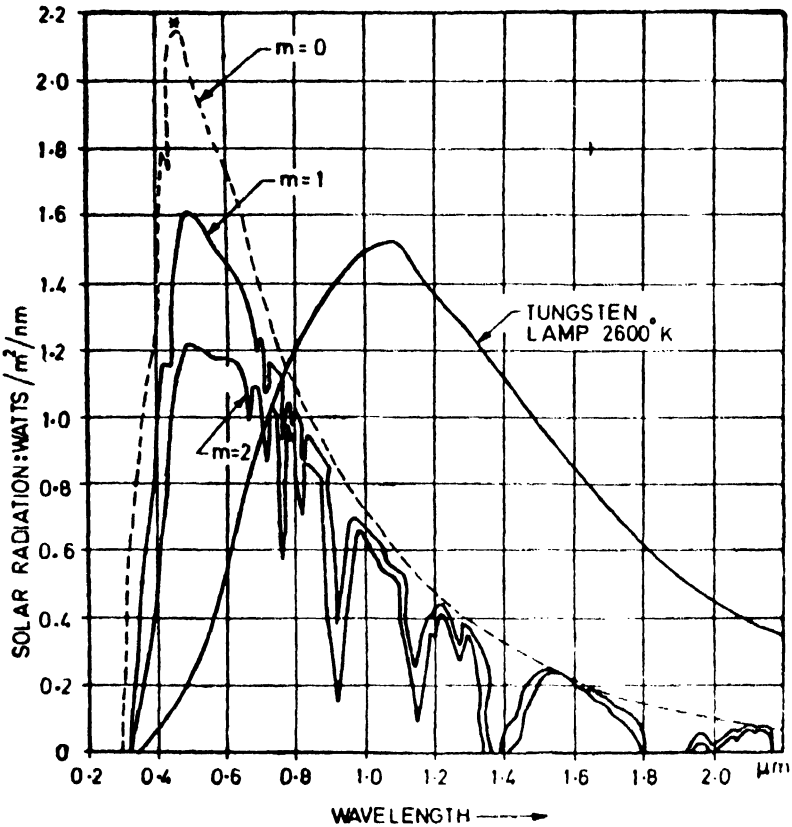
E_{ex} = irradiance from the test source,

α_{es} = absorptance of the specimen for the global radiation of sun and sky, and

α_{ex} = absorptance of the specimen for the radiation from the test source.

---

*Environmental tests for electronic and electrical equipment : Part XVII Simulated solar radiation at ground level.



*m = Air mass.

FIG. 1 RADIATION FROM TUNGSTEN LAMP COMPARED WITH SOLAR RADIATION

4. TEST PROCEDURE AND DURATION

4.1 Consideration shall be given to the duration of exposure and whether it should be continuous or intermittent. Three alternative procedures are specified:

a) *Procedure 'A'* — A 24-hour cycle, with 8 hours irradiation and 16 hours darkness, repeated as required. This gives a total irradiation of 8·96 kWh/m² per diurnal cycle, which approximates to the most severe natural conditions. Procedure 'A' should be specified where the principal interest is in thermal effects.

b) *Procedure 'B'* — A 24-hour cycle, with 20 hours radiation and 4 hours darkness, repeated as required. This gives a total irradiation of 22·4 kWh/m² per diurnal cycle and is applicable where the principal interest is in degradation effects.

c) *Procedure 'C'* — Continuous irradiation, as required. A simplified test, applicable where cyclic thermal stressing is unimportant and photochemical effects only are to be assessed; also for the assessment of heating effects on specimens with low thermal capacity.

4.2 The level of irradiance, as prescribed in IS:2106 (Part XVII)-1973*, is 1·120 kW/m² ± 10 percent. Acceleration of the test by increasing the irradiation above this level is not recommended. As stated above, the total daily irradiation approximating the most severe natural conditions is simulated by Procedure 'A' with a duration of exposure to the standard irradiation conditions of 8 hours per day. Thus, exposure for periods in excess of 8 hours will effect acceleration over natural conditions. However, continuous exposure of 24 hours per day (Procedure 'C') might mask any degradation effects of cyclic thermal stressing, and this procedure is not therefore generally recommended in this instance.

4.3 The duration called for will depend on the object of the test. Where the interest is in heating effects only, then 3 cycles should be adequate (except for large equipments which may require longer to attain maximum internal temperatures). A much longer test duration is necessary if degradation effects are to be assessed.

5. OTHER ENVIRONMENTAL FACTORS TO BE CONSIDERED

5.1 Temperature Within the Enclosure — The temperature within the enclosure during irradiation and darkness periods shall be controlled in accordance with the Procedure ('A', 'B' or 'C') specified. The relevant specification should state whether +40°C or +55°C is to be attained during irradiation, depending on the proposed usage of the equipment or component.

5.2 Humidity — Different humidity conditions may markedly affect photochemical degradation of materials, paints, plastics, etc, but requirements are so varied that no attempt has been made here to give guidance on this matter. Individual requirements should be clearly stated in the relevant specification, for example, a 4-hour period of damp heat (40 ± 2°C and 93 ± 3 percent RH) could be specified at the commencement of test procedure 'B'.

*Environmental tests for electronic and electrical equipment : Part XVII Simulated solar radiation at ground level.

5.3 Surface Contamination — Dust and other surface contamination may significantly change the absorption characteristics of irradiated surfaces. Unless otherwise required, specimens should be tested in a clean condition. However, if effects of surface contamination are to be assessed, the relevant specification should include the necessary information on preparation of surfaces, etc.

5.4 Ozone and Other Contaminating Gases — Ozone, generated by short wavelength ultra-violet radiation of test sources, will normally be excluded from the test enclosure by the radiation filter(s) used to correct the spectral energy distribution. As ozone and other contaminating gases may significantly affect the degradation processes of certain materials, it is important to exclude these gases from the test enclosures, unless otherwise required by the relevant specification (*see also* **10.3**).

5.5 Air Velocity — Attention is drawn to the possible cooling effects of air flow over the specimens This may also result in misleading errors in open-type thermopiles used to monitor radiation intensity. An air flow of as little as one metre per second may effect a reduction in temperature rise of over 20 percent. It is, therefore, essential to control and measure the rate of air flow, which should be as low as possible consistent with achieving satisfactory control of temperature (and humidity, where applicable). Adjustment of the temperature within the enclosure by suitable heating and cooling of the walls of the enclosure eliminates the need for high air velocities.

However, in practice, high solar radiation conditions are rarely accompanied by complete absence of wind. It may be necessary, therefore, to access the effect of different air velocities over an equipment or component under test. The relevant specification should state any special requirements in this respect.

5.6 Substrate, Mounting Attitude, etc - As the thermal properties of the substrate and method of mounting may significantly affect the temperature rise of the test specimen(s), these factors shall be carefully considered, so that the heat transfer is representative of typical use. The specimen(s) will probably be required to be mounted either on raised supports or on a substrate of specified properties, for example, a layer of concrete of specified thickness or a sand bed of certain conductivity, etc. Full details of the substrate, method of mounting and attitude of the specimen(s) should be given in the relevant specification (*see also* Appendix B).

6. RADIATION SOURCES

6.1 General — The radiation source may comprise one or more lamps and their associated optical components, for example, reflectors, filters, etc, to provide the required spectral distribution and irradiance.

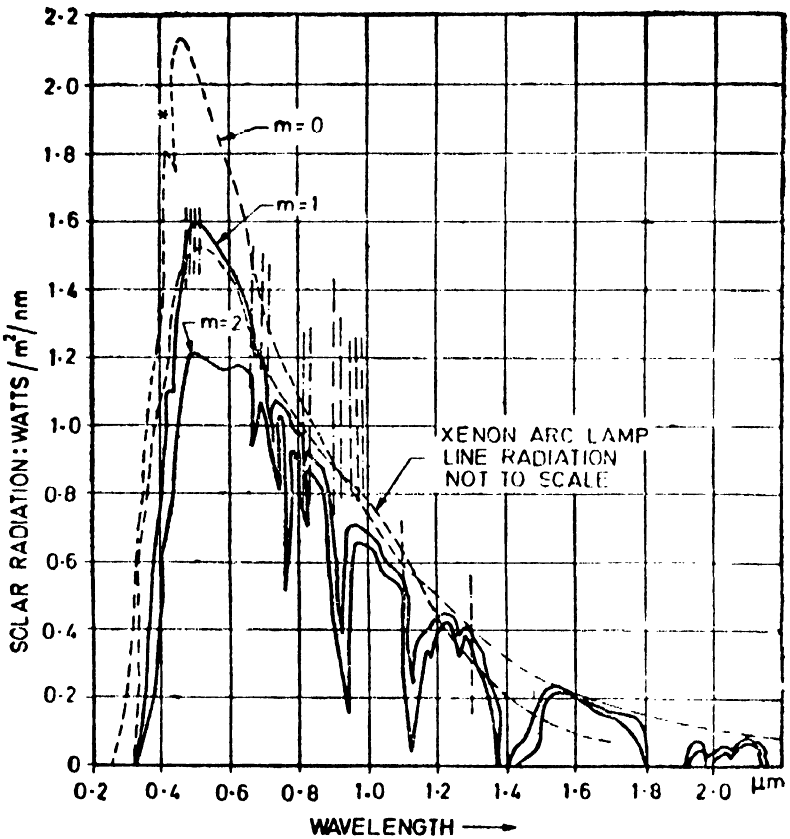
6.1.1 The high pressure xenon arc lamp with filters may provide the best match. Mercury vapour and xenon-mercury lamps have considerable deficiencies in matching which may lead to errors. The carbon arc, with specially doped electrodes, has been widely used but presents difficulties as regards stability and maintenance and is, therefore, not generally favoured. Tungsten filament lamps may be used if only thermal effects are of interest, but are almost completely deficient in ultra-violet radiations and therefore cannot be used where photochemical effects are to be assessed.

6.1.2 Characteristics of these lamps, features of filters, optical arrangements, etc, are covered in **6.2** to **6.7**.

6.2 Xenon Lamps — The configuration and size of the lamp(s) used will depend on the test required. A typical spectral distribution from a xenon arc is given in Fig. 2. However, the radiation direct from the hot electrodes should also be considered. This effect is proportionally much greater with short arcs than with long arcs and may considerably influence the spectral match, since radiation from the electrodes has a higher proportion of infra-red radiations than that from the arc. The relative spectral distribution of the xenon arc radiation has been found to be substantially independent of lamp power. However, variation of lamp power will change the temperature of the electrodes and hence the spectral distribution of their radiation. With long arc lamps, it is relatively simple to mask off the electrode radiation. The form of construction of the short arc lamp leads to considerably wider manufacturing tolerances than those of the long arc, a point of particular importance when replacement becomes necessary.

Routine replacement of either type of lamp will be needed, since the emission will change continuously with life and there may be quite wide variations of the life characteristic from lamp to lamp. Despite these variations in intensity, the relative spectral distribution of the arc radiation should remain practically unchanged, because xenon is a pure elemental gas.

6.3 Tungsten Filament Lamps - Because of their deficiency of ultra-violet radiation, tungsten lamps are unsuitable for tests for degradation purposes. Serious discrepancies may also occur in results obtained in tests for thermal effects, unless the considerable difference in spectral energy distribution compared with natural solar radiation are taken into account (*see also* **3.3**). The spectral distribution curve for a typical tungsten lamp at a filament temperature of 2 600°K, is shown in Fig 1, compared with natural solar radiation. The major part of the radiant energy from the tungsten lamp is in the infra-red region with maximum intensity at about 1·0 μm, whereas approximately 50 percent of solar energy is in the visible and ultra-violet bands, that is, at wavelengths less than 0·7 μm. The quartz halogen type of tungsten lamp has an improved consistency of performance during its life.



*m - Air mass.

FIG. 2 RADIATION FROM TYPICAL HIGH PRESSURE XENON ARC LAMP COMPARED WITH SOLAR RADIATION

6.4 Carbon Arc — Under certain conditions, the carbon arc may be made to provide radiation of a spectral distribution somewhat similar to that of the sun, as observed at ground level but correcting filters are needed, especially in the ultra-violet region. The combustible nature of the source has the disadvantages of lack of precise location and the impermanence. Perhaps the greatest disadvantage of the carbon arc is its burning away. Even with a carefully arranged feed mechanism, the continuous burning time is unlikely to exceed 5 hours.

6.5 Mercury Vapour Lamps — Mercury vapour lamp radiation is deficient in the red and infra-red portions of the spectrum and the spectrum has some very high energy lines. They have been used in conjunction with tungsten filament lamps in solaria, and a combined mercury-xenon arc source has been used for environmental testing purposes. However, the strong spectral lines make the mercury arc generally unacceptable as a simulated solar source.

6.6 Filters

6.6.1 Liquid filters have certain disadvantages, such as the possibility of boiling, the temperature coefficient of spectral transmission, and long term drift in spectral character. The present preference is therefore for glass filters to be used, although fundamentally a glass is not so accurately reproducible as a chemical solution. Some trial and error may be necessary to compensate for different optical densities by using diffierent plate thicknesses. Glass filters are proprietary articles and manufacturers should be consulted concerning the choice of filters suitable for particular purposes. The choice will depend on the source and its method of use. For example, a xenon source may be best compensated by a combination of infra-red and ultra-violet absorbing filters.

6.6.2 Some glass infra-red filters may be prone to rapid changes in spectral characteristics when exposed to excessive ultra-violet radiation. This deterioration may be largely prevented by interposing the ultra-violet filter between the source and the infra-red filter. Interference type filters, which function by reflecting instead of absorbing the unwanted radiation, thus resulting in reduced heating of the glass, are generally more stable than absorption filters.

6.7 Uniformity of Irradiance — Owing to the distance of the sun from the earth, solar radiation appears at the earth's surface as an essentially parallel beam. Artificial sources are relatively close to the working surface and means of directing and focussing the beam shall be provided with the aim of providing a uniform irradiance at the measurement plane within specification limits (that is, 1·120 $kW/m^2 \pm 10$ percent). This is difficult to achieve with a short-arc xenon lamp with a parabolic reflector, on account of shadows from the lamp electrodes and supports. Also, the incandescence of the anode may produce considerable radiation at a much lower colour temperature, slightly displaced from the main beam, if only the arc itself is at the focus of the reflector. Uniform irradiation is more readily achieved with a long-arc lamp mounted in a parabolic trough type reflector. However by employing very elaborate mounting techniques it is possible to irradiate, with some degree of uniformity, a large surface by a number of short-arc xenon lamps.

6.7.1 It is genearlly advisable to locate radiation source(s) outside the test enclosure or chamber. This avoids possible degradation of the optical components, for example by high humidity conditions, and contamination of test specimens by ozone generated by xenon and other types of arc lamps. In this case, the spectral transmittance of the window material shall be taken into account.

6.7.2 Precise collimation of the radiation beam is not normally necessary except for testing special equipment, such as solar cells, solar tracking devices, etc. However, some of the simulation techniques developed for space research purposes could be adapted for earth-surface solar radiation studies.

7. INSTRUMENTATION

7.1 Measurement of Irradiance — The type of instrument considered most suitable for monitoring the irradiance is a pyranometer as used for measuring combined solar and sky radiation on a horizontal plane.

7.1.1 Two types are suitable for measuring radiation from a simulated solar source. Each depends for its operation on thermojunctions.

7.1.1.1 *Moll-Gorczinski pyranometer* — The Moll-Gorczinski pyranometer consists of 14 constantan-manganin strips ($10 \times 1 \times 0{\cdot}005$ mm) arranged so that their 'hot' junctions lie on a plane and are formed into a horizontal surface by means of a black varnish of low thermal conductivity.

The 'cold' junction ends are bent down to make good thermal connections with a copper plate of large thermal capacity. The sensitive area is surmounted by two concentric glass hemispheres.

7.1.1.2 *Eppley pyranometer* — The Eppley pyranometer consists of two concentric rings of 0·25 mm silver foil. The inner ring is painted black (to absorb nearly all the radiation) and the outer ring is whitened (to reflect the visible and near infra-red radiation). The hot and cold junctions are thermally attached to the rings which are enclosed in a 76-mm diameter glass bulb filled with dry air.

Neither of these instruments are significantly affected by long-wave infra-red radiation emitted by the specimen or the test enclosure.

7.1.2 A modification of the Moll-Gorczinski pyranometer, commonly known as the Kipp solarimeter, is the instrument used by meteorological services in many countries. The Eppley pyranometer is the one most widely used in the United States. The glass covers used in both these instruments will cut off radiation at wavelengths greater than about 3 μm; this is only significant when unfiltered tungsten lamps are used and a correction factor would then be necessary.

7.2 Measurement of Spectral Distribution — Total intensity checks are readily made, but detailed checks on spectral characteristics are more difficult. Major spectral changes may be checked by inexpensive routine measurements using a pyranometer in conjunction with selective filters. For checking the detail spectral distribution characteristics of the facility it would be necessary to employ sophisticated spectroradiometric instrumentation. However, there seems to be no practical obstacle to prevent this calibration being done either as a service by the facility manufacturer or by visit from a national calibration centre. Correlation would be achieved between the filter/pyranometer and spectroradiometric methods at regular intervals.

7.2.1 Changes in the spectral characteristics of lamps, reflectors and filters may occur over a period of time which could result in the spectral distribution being seriously outside the permitted tolerances. Manufacturing tolerances may mean that lamp replacement could result in unacceptable changes in both the level of irradiation and spectral distribution compared with that initially set up. Regular monitoring is therfore essential, but monitoring of the detail spectral distribution within the test facility may not be possible while a specimen is undergoing test.

7.3 Measurement of Temperature — Because of the high level of radiation it is essential that temperature sensors are adequately shielded from radiant heating effects. This applies both to measuring air temperatures within the test enclosure and also to monitoring specimen/equipment temperatures.

7.3.1 For air temperature measurements, it is obviously impracticable to use the standard 'Stevenson' screen used for meteorological measurements of 'shade temperature' as this is too cumbersome. A suitable alternative is a thermocouple freely mounted in a radiation shield comprising a vertical cupro-nickel tube (approx 1·5 cm dia × 7 cm) surmounted by a spaced metal hood, polished on the inside surface and painted white on the outside.

7.3.2 When monitoring equipment temperatures, sensors, such as thermocouples, should be located on the inside surfaces of the external case and not be attached to the outside surfaces. Temperature indicating paints and waxes are unsuitable for monitoring the temperature of irradiated surfaces of specimens, as their absorption characteristic will not be the same as that of the specimens.

8. PREPARATION OF TEST FACILITY AND SPECIMENS

8.1 Test Facility — It should be ensured that the optical parts of the facility, lamps, reflectors and filters, etc, are clean.

The level of irradiation over the specified measurement plane shall be measured immediately prior to each test.

Any ancillary environmental conditions, for example, ambient temperature, humidity, air velocity and other parameters, if specified, should be monitored continuously throughout the test.

8.2 Specimens — The method of mounting and the aspect of the specimen relative to the direction of radiation will have marked influences on the heating effects. The specimens will probably be required to be mounted either on raised supports or on a substrate of specified properties, for example, a layer of concrete of specified thickness or a sand-bed of certain conductivity. All this and the attitude of the specimens should be specified in the relevant specification.

8.2.1 Special attention shall be paid to the surface conditions of the specimens to see that their finish is clean or in accordance with the relevant specification requirements. The heating effect on the specimens under test will be largely affected by the condition of the surfaces of the specimens. Care should therfore be exercised in handling the specimens, especially in avoiding oil-films and in ensuring that the surface finish and its underlay are fully representative of production standards. Temperature sensors should be attached to specimens as required (*see also* **7.3**).

9. INTERPRETATION OF RESULTS

9.1 Compliance with Specification — The relevant specification should indicate the permitted changes in the external condition and/or performance of the specimen(s) under test after exposure to the required level of irradiation for specified durations. In addition to such mandatory requirements, the following aspects of interpretation may be considered.

9.2 Comparison with Field Experience — The deterioration effects of exposure of materials and equipment to sunlight are well documented (*see also* **9.5** and **9.6**). Any marked difference between these effects and the behaviour under simulated conditions should be investigated and the basic cause established, namely, whether caused by the test equipment or procedure, or by some peculiarity in the specimens.

9.3 Short Term Effects — Primarily, heating effects are concerned. Short term effects to be looked for will mainly be in the nature of local overheating.

9.4 Long Term Effects — The purpose of carrying out long term tests is to determine the pattern of deterioration with the two objectives of seeing whether there is an initial rapid change and of assessing the useful life of the item under test.

9.5 Thermal Effects — The maximum surface and internal temperatures attained by a specimen or equipment will depend on:

a) temperature of ambient air;
b) intensity of radiation;
c) air velocity;
d) duration of exposure; and
e) the thermal properties of the object itself, for example, surface reflectance, size and shape, thermal conductance and specific heat.

Equipment may attain temperatures in excess of 60°C, if fully exposed to solar radiation in an ambient temperature as low as 35 to 40°C. The surface reflectance of an object affects its temperature rise from solar heating to a major extent; changing the finish from say a dark colour to a gloss white will effect a considerable reduction in temperature. Conversely, a pristine finish designed to reduce temperature may be expected to deteriorate in time resulting in an increase in temperature.

Most materials are selective reflectors, that is, their spectral reflectance changes with wavelength. For instance, paints, in general, are poor infra-red reflectors although they may be very efficient in the visible region. Furthermore, the spectral reflectance of many materials change sharply in the visible (producing a colour sensation to the human eye) and in the near infra-red regions. It is important, therefore, that the spectral energy distribution of the radiation source(s) used in any simulated test should closely duplicate that of natural solar radiation, or that appropriate adjustment of the irradiance is made so that the same heating effect is obtained (*see* **3.3** and Appendix A).

9.6 Degradation of Materials — The combined effects of solar radiation, atmospheric gases, temperature and humidity changes, etc, are often collectively termed 'weathering' and result in the 'ageing' and ultimate destruction of most organic materials (for example, plastics, rubbers, paints, timber, etc).

9.6.1 Many materials, which give satisfactory service in temperate regions, have been found to be completely unsuitable for use under the more adverse conditions of the tropics. Typical defects are the rapid deterioration and breakdown of paints, the cracking and disintegration of cable sheathing and the fading of pigments.

9.6.2 The breakdown of a material under weathering usually results not from a single reaction, but from several individual reactions of different types occurring simultaneously, often with interacting effects. Although solar radiation, principally the ultra-violet, resulting in photo-degradation is often the major factor, its effects may seldom be separated in practice from those of other weathering factors. An example is the

effects of ultra-violet radiation on polyvinyl chloride, where the apparent effect of ultra-violet radiation alone is small, but its susceptibility to thermal breakdown, in which oxygen probably plays a major role, is markedly increased.

9.6.3 Unfortunately, artificial tests occasionally produce abnormal defects, which do not occur under natural weathering. This may often be attributed to one or more of the following causes:

a) Many laboratory sources of ultra-violet radiation differ considerably from natural solar radiation in spectral energy distribution.

b) When the intensity of ultra-violet radiation, temperature, humidity, etc, are increased to obtain an accelerated effect, the rate of the individual reactions, which occur under normal exposure conditions, are not necessarily increased to the same extent.

c) The artificial tests, in general, do not simulate all the natural weathering factors.

10. HAZARDS AND PERSONNEL SAFETY

10.1 General — The complex equipment employed for solar radiation testing purposes will necessarily call for operation and maintenance by a skilled test staff, not only to ensure the correct prescribed performance of the test but also by reason of the various health and safety hazards that have to be taken into account.

10.2 Ultra-Violet Radiation — The most obvious dangers that have to be guarded against are those associated with the harmful effects of high intensity radiation in the near ultra-violet region.

10.2.1 In natural sunlight, the eyes are protected in two ways; the brightness of the sun makes it almost impossible to look directly at it, and the ultra-violet radiation is considerably attenuated by the atmosphere. These protections may not apply to artificial sources. The eyes shall be protected by filtered goggles or viewing apertures, particularly when setting up the equipment. All testing personnel should be warned that severe eye damage may result from only short exposure to unfiltered radiation from arc type lamps. Serious erythema (sunburn) or exposed skin will also occur. Koller states that ultra-violet radiation of sunlight is a major casual factor in cancer of the skin in the white population of the USA. The use of suitable protective clothing including protection of the head and hands is therefore recommended, even when working in test enclosures irradiated by filtered sources.

10.3 Ozone and Harmful Fumes — Another serious health hazard arising from the use of xenon and other arc lamps is the possible build-up of local toxic concentrations of ozone during the testing period. However, the maximum production of ozone occurs at the initial switching on of the lamps, and thereafter the hot envelope of the lamp tends to degrade the ozone back to oxygen. Where forced air cooling is employed, this cooling air should be sucked out and removed from the building and not blown into the lamp housing. In this way, the ozone hazard will be largely eliminated. Concentrations of 1·0-10·0 parts per million by volume are known to cause headaches, irritation of the nose and throat and watering of the eyes. However, it shall be realised that the toxic concentration of ozone is less than 0·1 parts per million, which is below the level that is readily detectable by odour which is 0·5-1·0 parts per million. Suitable detecting and measuring equipment is commercially available.

10.3.1 The combined effects of heat and ultra-violet radiation on certain plastics (for example melamine laminates) may also produce toxic fumes. Particular care should therefore be taken in the choice of materials used in the construction of a test facility.

10.4 Risk of Lamp Explosions — The use of high pressure xenon discharge lamps as the primary radiation source may also result in serious accidents unless a well planned code of practice for the handling of these arc discharge tubes has been laid down and is adhered to. All such lamps (whether hot or cold, used or new) have a liability to explode violently by reason of the considerable internal pressure (two to three atmospheres when cold, but up to 20 atmospheres when hot). There should be no visible dirt or oil on the surface, so regular cleaning with the detergent and alcohol is necessary using cotton gloves and face protection during such cleaning. When cold lamps are to be stored, the effects of explosion may be limited by two layers of 0·25 mm thick plastic sheet. Particular care shall be taken to limit the spread of chain reaction breakdowns in multi-lamp equipments. It is possible to use armour plate glass for the dual purpose of protection against lamp explosions and as a corrective filter.

Individual lamp records should be kept as a matter of routine so as to be able to detect abnormal voltage/current behaviour.

10.5 Electric Shock — Normal electric shock preventive measures shall of course be adopted, particularly in the case of the high voltage ignitor systems used with arc lamps. In some xenon lamps, the arc ignition pulse exceeds 60 kV, and an interlock system is therefore essential.

APPENDIX A

(*Clauses* 3.3 *and* 9.5)

CALCULATION OF ADJUSTMENT TO IRRADIANCE

A-0. This is applicable for radiation sources having a spectral distribution not in accordance with Table 1 of IS : 2106 (Part XVII)-1973* (permissible only when the test is made solely to assess thermal effects.)

A-1. In order to obtain an equivalent heating effect, the irradiance from the test source, E_{ex}, shall be adjusted, so that :

$$E_{ex} = 1 \cdot 120 \frac{\alpha_{es}}{\alpha_{ex}} \text{ kW/m}^2$$

where

α_{es} = absorptance of the specimen for the global radiation of sun and sky, and

α_{ex} = absorptance of the specimen for the radiation from the test source.

A-2. The absorptance factors α_{ex} and α_{es} may be calculated from the formula:

$$\alpha_{ex} = \frac{\int_0^\infty S\lambda_x \cdot \alpha(\lambda) \, d\lambda}{\int_0^\infty S\lambda_x \cdot d\lambda}$$

$$\alpha_{es} = \frac{\int_0^\infty S\lambda_s \cdot \alpha(\lambda) \cdot d\lambda}{\int_0^\infty S\lambda_s \cdot d\lambda}$$

where

$S\lambda_x$ = spectral distribution of the test source,

$\alpha(\lambda)$ = spectral absorptance of the specimen, and

$S\lambda_s$ = spectral distribution (*see* Note) of global radiation of sun and sky.

NOTE — For calculation purposes use the more detailed information given in Table 1.

*Environmental tests for electronic and electrical equipment : Part XVII Simulated solar radiation at ground level.

Table 1 Detailed Spectral Distribution of Global Radiation for Calculation Purposes

(*Clause* A-2)

Spectral Region	Bandwidth µm	Irradiance W/m²	Irradiance Percentage
(1)	(2)	(3)	(4)
Ultra-violet B*	0·28 - 0·32	5	0·4
Ultra-violet A	0·32 - 0·36	27	2·4
	0·36 - 0·40	36	3·2
Visible	0·40 - 0·44	56	5·0
	0·44 - 0·48	73	6·5
	0·48 - 0·52	71	6·4
	0·52 - 0·56	65	5·8
	0·56 - 0·64	121	10·8
	0·64 - 0·68	55	4·9
	0·68 - 0·72	52	4·6
	0·72 - 0·78	67	6·0
Infra-red	0·78 - 1·0	176	15·7
	1·0 - 1·2	108	9.7
	1·2 - 1·4	65	5·8
	1·4 - 1·6	44	3.9
	1·6 - 1·8	29	2·6
	1·8 - 2·0	20	1·8
	2·0 - 2·5	35	3·1
	2·5 - 3·0	15	1·4
		1 120	100·0

*Radiation shorter than 0·30 µm reaching the earth's surface is insignificant.

A-3. For non-radiation transmitting specimens:

$$\alpha(\lambda) = 1 - \rho(\lambda)$$

where

$\rho(\lambda)$ = spectral reflectance factor of the specimen.

NOTE — The spectral absorptance of a surface shall normally be determined from spectral reflectance data. Several commercial instruments are available for spectral reflectance measurements, using the monochromator/integrating (Ulbricht) sphere method.

APPENDIX B

(*Clause* 5.6)

HEAT TRANSFER THROUGH SUBSTRATE

B-1. In order to specify an appropriate substrate material it may be necessary to estimate the probable heat transfer through the substrate.

B-2. If its thermal conductivity k is known, the heat flow rate q through a substrate of thickness L and surface area A, having a temperature difference of $\triangle T$°C between faces, may be calculated from the formula:

$$q = \frac{k.A. \triangle T}{L} \text{ watts}$$

This formula ignores convention and radiation effects which will usually (but not necessarily) be of secondary importance.

B-3. The thermal conductivities of some common materials are given in Table 2.

Table 2 Thermal Conductivities of Common Materials

MATERIAL	TEMPERATURE, °C (*See* NOTE)	THERMAL CONDUCTIVITY W.m.$^{-1}$$k^{-1}$ TEMPERATURE DIFFERENCE
(1)	(2)	(3)
Silver	20	411
Copper — very pure	20	395
Copper — commercial	20	372
Gold — pure	20	311
Aluminium	20	229
Duralumin	20	165
Magnesium — pure	20	143
Elektron	20	116
Brass	20	81 116
Zinc	20	113
Tin	20	66
Iron — wrought, pure	0	59
Iron	200	52
Iron — cast 3 percent carbon	20	58
Iron — chrome steel	20	40
Iron — nickel chrome steel	20	14·5
Nickel	18	59·5
Nickel — silver (Ni-Cu-Zn)	0	29·3
Lead — pure	0	35·1
Graphite — compact	20	12-174
Fireclay	100	0·5 1·2
Boiler scale	100	0·08-2·3
Concrete	20	0·8-1·4
Brick — dry	20	0·38-0·52
Plate glass	20	0·76
Marble	20	2·8
Bakelite	20	0·233
Rubber	20	0·13-0·23
Plexiglass	20	0·184
Celluloid	20	0·215
Beechwood (along grain)	20	0·35
Oak (cross grain)	20	0·17-0·21
Oak (along grain)	—	0·37
Pine (cross grain)	20	0·14
Pine (along grain)	—	0·26

NOTE — This is the temperature at which the thermal conductivity of the material was measured. For practical purposes there will be little difference over the substrate temperature range likely to be obtained in IS : 2106 (Part XVII) - 1973 'Environmetal tests for electronic and electrical equipment : Part XVII Simulated solar radiation at ground level'.

BUREAU OF INDIAN STANDARDS

Headquarters:

Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002
Telephones : 331 01 31, 331 13 75 Telegrams : Manaksanstha

(Common to all Offices)

Regional Offices :	Telephone
Central : Manak Bhavan, 9 Bahadur Shah Zafar Marg NEW DELHI 110002	331 01 31 331 13 75
Eastern : 1/14 C.I.T. Scheme VII M, V.I.P. Road, Maniktola, CALCUTTA 700054	37 84 99, 37 85 61 37 86 26, 37 86 62
Northern : SCO 445-446, Sector 35-C CHANDIGARH 160036	53 38 43, 53 16 40 53 23 84
Southern : C. I. T. Campus, IV Cross Road MADRAS 1600113	235 02 16, 235 04 42 235 15 19, 235 23 15
Western : Manakalaya, E9 MIDC, Marol, Andheri (East), BOMBAY 400093	632 92 95, 632 78 58 632 78 91, 632 78 92

Branches : AHMADABAD. BANGALORE. BHOPAL. BHUBANESHWAR. COIMBATORE. FARIDABAD. GHAZIABAD. GUWAHATI. HYDERABAD. JAIPUR, KANPUR. LUCKNOW. PATNA. THIRUVANANTHAPURAM.

Printed at Printwell Printers, Aligarh, India